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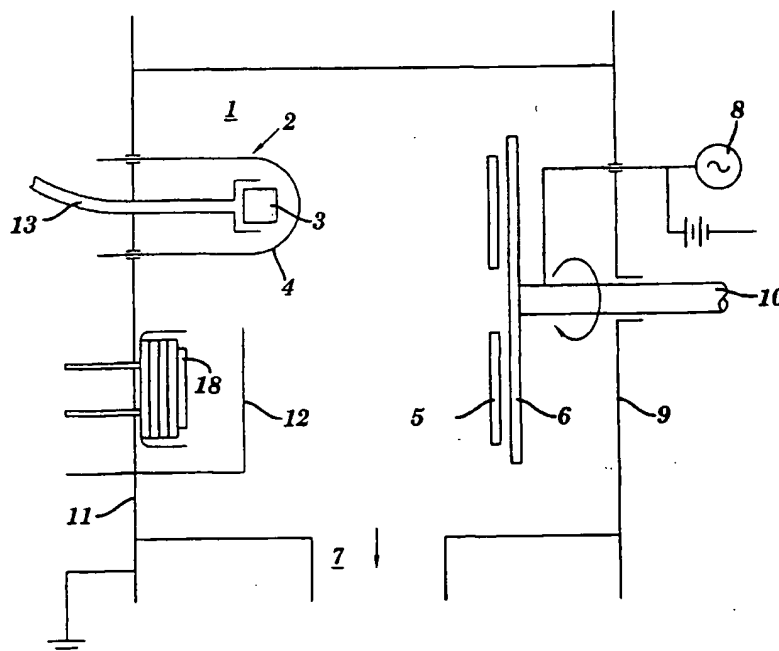
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(54) Title: WEAR-RESISTANT ELECTROMECHANICAL CONTACTS



(57) Abstract: The present invention relates to an electromechanical contact (20) which includes a substrate (24), a diamond-like coating (22) which includes carbon, silicon, and a metal. The present invention further relates to a method of making the electro-mechanical contact.



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## WEAR-RESISTANT ELECTROMECHANICAL CONTACTS

This application claims the benefit of U.S. Provisional Patent Application Serial No. 60/116,489, filed January 20, 1999, incorporated herein by  
5 reference.

### FIELD OF THE INVENTION

The present invention relates to electromechanical contacts and  
10 methods of making electromechanical contact.

### BACKGROUND OF THE INVENTION

Electromechanical contacts are devices that utilize the electrical and  
15 mechanical properties of materials simultaneously to perform a desired function. Electromechanical contacts frequently are used in position-sensing devices, digital encoders, and motor armatures. These electromechanical contacts are required to be rugged, reliable, possess good thermal stability, resistant to wear, vibration and shock, and operate in a variety of environments. Specifically, one example of an  
20 electromechanical contact comprises a substrate coated with a resistive pattern, a metal layer, and a multi-fingered contact to complete the circuit.

Presently, screen printing technology is used to deposit resistive and conductive patterns on suitable substrate materials such as, for example, alumina, glass, and brass, to make electromechanical contacts. The resistive patterns are made  
25 with materials such as graphite impregnated polyimides and the conductive patterns are made with palladium silver. The deposited screen printed thicknesses range from 5 to 20 microns ( $\mu\text{m}$ ). However, the use of palladium silver as a conductive material is expensive and increases the overall cost of the contact. Further, to extend the life and smooth functioning of the electromechanical contacts, lubricants are used.  
30 However, these lubricants can become viscous at very low temperatures or after extended use, and result in loss of reliability. As a result, the typical life expectancy of position sensing electromechanical contacts is 25 to 50 million cycles.

Thus, the use of lubricants and the cost and wear of the resistive and conductive patterns are significant problems with the present electromechanical

contact technology. The present invention is directed to overcoming these deficiencies.

## SUMMARY OF THE INVENTION

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The present invention relates to an electromechanical contact which includes a substrate and a diamond-like coating which includes carbon, silicon and a metal where the diamond-like coating forms a resistive pattern on the substrate.

10 The diamond-like coatings used for making the resistive patterns of electromechanical contacts not only have the potential to increase the life of the electromechanical device but also promote elimination of hazardous lubricants. The coating may include C, H, Si, O and a metal, the ratios of which are tailored to the particular electromechanical device of interest. The coating thickness and the patterning are also application specific. These diamond-like coatings are extremely  
15 hard, wear resistant, long lasting, and are electrically conductive. The coating can be deposited on a variety of substrate materials such as glass, alumina, and brass and on conductive patterns with excellent adhesion and low film stress.

Another aspect of the invention relates to a method for making an electromechanical contact which includes providing a substrate and depositing a  
20 diamond-like coating which includes carbon, silicon and a metal on the substrate.

The benefits achieved by the electromechanical contacts of the present invention overcomes the problems of the present electromechanical contact technology by eliminating the use of lubricants and increasing the life expectancy of the electromechanical contacts, thereby lowering cost.

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## BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a coating chamber used for depositing the diamond-like carbon-containing coatings on a substrate.

30 Figure 2 is a schematic of an electromechanical contact made in accordance with the present invention and a hoe type contactor.

Figure 3 is a schematic process diagram showing a series of steps taken to fabricate an electromechanical contact made in accordance with the present invention.

## DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to an electromechanical contact which  
5 includes a substrate and a diamond-like coating which includes carbon, silicon and a metal where the diamond-like coating forms a resistive pattern on the substrate.

In a first embodiment, the present invention contemplates using any wear-resistant diamond-like coating on an electromechanical contact. In one embodiment, the coating includes carbon, hydrogen, and a metal. In an alternate  
10 embodiment, the coating includes carbon, silicon and a metal. Any metal may be utilized. Preferred metals include titanium and tungsten. One particularly preferred coating comprises a random carbon network chemically stabilized by hydrogen atoms, a glass-like silicon network stabilized by oxygen atoms, and a metallic network.

15 In one embodiment of the present invention, the diamond-like coating is electrically tunable. Depending upon the electrical resistivity required in a particular application, the preferred coatings may have one or more separate disordered networks of dopants designed to tailor or tune the resistance. The dopants may be any one or a combination of the transition metals and non-metals of the  
20 Groups 1-7b and 8 of the periodic table. The network elements other than the C-H network may be referred to as alloying elements. Further, silicon and oxygen atoms may also be used in the dopant networks with other elements and compounds, such as Ti, W and Cr.

Therefore, the preferred materials used to coat electromechanical  
25 contacts, as described herein, may comprise either a two component network, the diamond-like C-H network with a metal network; a three component network comprising the Si-O and C-H networks with a metal network; or four or more component network, which include a C-H network, a metal network, a Si-O network and one or more dopant networks. It is understood that although at least one of the  
30 networks of the coating is metallic, the dopant networks could be both non-metal and metal dopant networks.

The properties of these materials can be varied over wide ranges depending on the dopant and the concentration selected, as well as the deposition technique and parameters. As already mentioned, the structure of these composites

can be tailored at the molecular level. Therefore, unique mechanical and other desirable solid state properties with desired electrical resistance can be imparted on the preferred coatings. Thus, the coatings of the present invention can be utilized as either resistive or conductive patterns, or both, of an electromechanical contact.

- 5 Illustrative is the electromechanical contact 20 shown in Figure 2. As shown in Figure 2, the coating of the present invention 22 forms a pattern on substrate 24. Patterned coating 22 works in conjunction with hoe type contactor 26 to form electromechanical contact 20.

- Preferred dopant elements to be used, if desired, in the coating network  
10 are B, Si, Ge, Te, O, Mo, W, Ta, Nb, Pd, Ir, Pt, V, Fe, Co, Mg, Mn, Ni, Ti, Zr, Cr, Re, Hf, Cu, Al, N, Ag and Au; with Ti and W being more preferred.

- The carbon content in the preferred diamond-like coatings of the present invention is greater than about 40 atomic % of the coating, preferably from about 40 to about 98 atomic %, more preferably from about 50 to about 98 atomic %.
- 15 Although such coatings may theoretically be prepared without any hydrogen, the hydrogen content is preferably at least about 1 atomic % up to about 40 atomic % of the carbon concentration. There is from about 0.01 to about 1.5 parts metal (plus dopants, if present), for every 1 part carbon, depending upon the desired characteristics to be imparted to the coating. The sum of the silicon, oxygen and  
20 dopants, if present, is greater than about 2 atomic % of the coating composition. In one preferred embodiment, the ratio of carbon to silicon atoms is from about 2:1 to about 8:1, hydrogen to carbon atoms is from about 0.01:1 to about 0.4:1, silicon to oxygen atoms is about 0.5:1 to about 3:1, and dopant to carbon atoms is about 0:1 to about 1.5:1. Therefore, in the coating network on an atomic % basis, for every 1 part  
25 carbon, there is from about 0.01 to about 0.4 parts hydrogen, from about 0.125 to 0.5 parts silicon, and from about 0.0375 to about 1.0 part oxygen

- In the preferred carbon-containing diamond-like coatings, the presence of the glass-like silicon-oxygen network serves 1) to prevent the growth of graphitic carbon at high temperatures; 2) to reduce the internal stress in the coating structure  
30 and thereby enhance the adhesion to substrates and 3) to reduce the coefficient of friction of the coating at ambient and high humidity.

Optionally, a metal layer may be deposited underneath the preferred coatings of the present invention for use as bottom electrical contacts. The metal layer may be selected from the group consisting of Cr, Au, Ag, and Ti.

The preferred coatings of the present invention are diamond-like carbon-containing coatings synthesized via a glow discharge plasma process as would be readily understood by one skilled in the field of thin film deposition. Carbon-containing particle beams can be produced by plasma discharge in a plasmatron and  
5 extracted as charged particles by a high-voltage field in a vacuum chamber and directed onto the substrate. The composition of the coatings of the present invention include but are not limited to the coatings that are the subject of U.S. Patent No. 5,466,431, the entire content of which is incorporated by reference herein.

Figure 1 shows one preferred embodiment of the coating chamber used  
10 for depositing the preferred diamond-like carbon-containing coatings. A vacuum deposition chamber 1 is provided to coat a substrate sample. The substrate may comprise glass, ceramics, such as alumina and silica, brass, polyimides, fluorocarbon polymers, such as tetrafluoroethylene and fluorinated ethylene-propylene resins, thermoplastics, such as polycarbonates, polyethylene terephthalate, polyamides, and  
15 acetal resins, other flexible polymers, or palladium silver. Further, substrates may be utilized which have a pre-existing resistive or conductive pattern. A precursor inlet system 2, comprises a metal tube 13 and a diffuser head 3 through which a liquid precursor, preferably a polysiloxane, is injected. The precursor inlet system 13 is shown incorporated into the chamber 1 through the chamber base plate 11. The  
20 precursor can also be introduced into the deposition chamber 1 by a liquid-to-vapor delivery system. With this delivery system, the precursor is flash evaporated into a vapor. A mass flow controller is used to precisely control the flow rate of the precursor vapor. While not required, a mixing gas, such as argon can be used to assist precursor evaporation. After the precursor is introduced into the deposition chamber  
25 1, the samples are loaded into the chamber through the load lock 9. Disposed within the chamber 1 is a resistively heated tungsten filament 4. Substrates 5 to be coated are attached to the substrate holder 6. The substrate holder 6 can be covered by a shutter (not shown) before deposition is initiated. Substrate 5 can be masked with a shadow mask (not shown) during deposition to create a desired pattern. The power  
30 supply 8 is used for biasing the substrates (DC, pulsed DC or RF). Additionally, a power supply (not shown) is used to bias the filament 4 and a power supply (not shown) is used to power a magnetron 18. In practice, the system is pumped down using normal vacuum pumpdown procedures. Gate valves (not shown) operably connected to port 7 are closed and the system is backfilled with dry air, nitrogen or

argon until the chamber reaches atmospheric pressure. The chamber is then opened and substrates 5 to be coated are attached to the substrate holder 6 using any fixtures or fastening means including clips, screws, clamps, and masks. The magnetron 18 is used for codeposition of metal and other dopants, and the magnetron 18 may be covered by a shutter 12 before deposition is initiated. The substrate holder 6 is designed in a way that it will also hold a cylinder sample (not shown), which, in operation, rotates both about the axis of the central drive shaft 10, and its own axis which is perpendicular to the drive shaft 10.

The high vacuum is achieved by roughing down the chamber with a mechanical pump followed by pumping with a high vacuum pump through port 7. The pump can be a diffusion pump, turbomolecular pump, cryogenic pump, or other high vacuum pumps known in the field of vacuum technology. The coatings required according to the process of the present invention can be carried out in a batch type process for small volumes. In such instance, the substrates are mounted on a substrate holder inside the deposition chamber, the chamber is evacuated, the deposition is performed, and the chamber is vented, followed by removal of the coated parts (substrates).

For larger volumes, the process of the present invention can be carried out in an air-to-air system. Such air-to-air system could consist of cleaning, transport of parts to the deposition chamber, and mechanized/robotic loading of the parts on the substrate holder. This is followed by entry of the substrate holder into the load-lock chamber, by entry into the deposition chamber, and coating. The coated parts on the substrate holder can then be removed from the deposition chamber. It is understood that the substrates to be coated may be rotated, tilted, or otherwise oriented, or manipulated while on the substrate holder, and at other instances during processing.

The chambers are evacuated to a base pressure below  $10^{-5}$  Torr after loading the substrates. Argon gas is then introduced into the chamber to raise the chamber pressure to  $10^{-3}$  Torr to  $10^{-4}$  Torr. The substrates are then argon ion cleaned inside the deposition chamber before coating.

The argon-ion cleaning is accomplished by either of two methods: glow discharge cleaning or filament assisted plasma cleaning. In glow discharge cleaning, the argon gas is introduced until the chamber pressure is in the  $10^{-3}$  Torr range. A glow discharge is excited by radio frequency (RF), pulsed direct current (PDC) or direct current (DC). During the discharge, a substrate bias of from about



0.03 to about 5.0 kV can be used. The frequency of the RF or pulsed DC is in the range of 90-450 kHz. For plasma cleaning, the argon ions are created by a hot filament discharge and the chamber pressure is in the  $10^{-4}$  Torr range. The temperature of the filament is in the range of from about 2100 °C to about 2950 °C, with a DC filament bias of from about 70 V to about 150 V. The substrates are biased by either RF, pulsed DC, or DC as mentioned above. Other ion sources known in the field of deposition coating can be used for ion generation, such as, Kauffman type ion sources and RF coil sources. In addition to argon ion etching, other plasma cleaning can be performed by the introduction of small amounts of oxygen gas in addition to the argon gas. This process has been found to efficiently remove hydrocarbon contamination, oxide layers, and other contaminants, as well as improving the adhesion of coatings deposited on some substrates.

Towards the end of the substrate cleaning, organosilicon precursors, preferably siloxanes which contain C, H, Si, and O, are introduced into the chamber. These precursors preferably have 1 to 10 silicon atoms. The preferred precursor is a polyphenylmethylsiloxane with 2-3-4 triphenyl-nonamethyl-pentasiloxane being particularly preferred. The precursor is introduced directly into the active plasma region using a microporous ceramic or metallic dispenser which is heated by the hot filament. The precursor can be mixed with other gases, both inert (argon as the feed gas) and active gases such as methane, acetylene, butane, tetrafluoromethane, perfluoroethane, etc. The hot filament photon and electron emission causes fragmentation and ionization of the precursor. The precursor can also be introduced into the system using liquid delivery systems consisting of a flow controller, a heater, and a dispenser as known in the field. In the case of liquid delivery systems, the source of electrons can be a hot filament isolated from the precursor delivery system. As already described, the precursor can be admitted to the chamber via vapor feed.

Metal-containing species can be incorporated into the growing films and coatings by many methods: (a) thermal evaporation; (b) ion sputtering; (c) ion beams, (d) magnetron sputtering, etc. The metal beams are directed toward the substrate by the appropriate placement of the sources.

Variations of the above described deposition process include: (a) the use of sputtered silicon and oxygen gas as sources for Si and O; (b) use of solid  $\text{SiO}_2$  as a source for Si and O; (c) use of  $\text{SiH}_4$  and oxygen-containing gases as sources for Si; (d) use of a graphite target, hydrogen, and hydrocarbon gases as sources of C and

H; and (e) use of metal-containing organosilicon compounds as sources of C, H, Si, O and metal. Combination of the aforementioned methods may be used.

The coating deposition can also be sustained by a RF capacitively coupled discharge (CCD). The organosilicon precursor can be introduced by either a  
5 separately heated microporous ceramic or metallic dispenser, or one of the liquid vapor injection systems described previously. The precursor can be mixed with other gases, both inert with argon as the feed gas, or active gases such as methane, acetylene, butane, etc., to achieve deposition pressures typically in the  $10^{-2}$  Torr range. A single plate or parallel plate configuration can be used. The substrates are  
10 attached to one of the plates. RF or PDC voltage is then applied. In the case of a capacitive RF discharge, the frequency of the RF is in the range of 100 kHz to 100 Mhz. In another method, a large RF antenna can be placed inside the chamber to excite the discharge. The antenna can be made of copper, stainless steel, or other known state of the art materials. A protective coating, such as porcelain, can be  
15 applied to the surface of the antenna to prevent sputtering. The formation of dopant-containing beams may be realized by any one of, or combination of, the following methods: 1) thermal evaporation; 2) ion-sputtering; 3) ion beams; 4) magnetron sputtering and the like. The dopant-containing beams are directed onto the growing film surface through the vacuum chamber. A DC or RF potential is generally applied  
20 to the substrates during the deposition process. No external substrate heating is required, but heating may be used if desired. The substrate holder may be designed specifically to hold parts of different shapes such as cylinders, as would be readily apparent to one skilled in the field. Useful variations of the above described deposition methods include the use of sputtered silicon and oxygen gas as precursors  
25 for silicon and oxygen, the use of sputtered carbon and hydrogen or hydrocarbon gas used as carbon and hydrogen precursors, or any combination thereof.

One example of a method of fabricating the electromechanical contact of the present invention is depicted in Figure 3. A first shadow mask 30 for first pattern 32 is made with a desired pattern. First shadow mask 30 is made of a material  
30 known to those of ordinary skill in the art, such as stainless steel. First shadow mask 30 is positioned above substrate 34 as shown in Figure 3A. First pattern material  $M_1$  is deposited as described above through shadow mask 30 such that first pattern 32 is deposited on substrate 34 in the pattern as shown in Figure 3B. In one embodiment, this layer is a metal layer. Optionally, this layer may be adhered to substrate 34 by

other techniques. Alternately, first pattern 32 is formed from the coating of the present invention.

Following the deposition of first pattern 32 by material  $M_1$ , a second shadow mask 36 with the desired pattern for second pattern 38 is positioned over substrate 34. Second shadow mask 36 is positioned such that there will be a partial overlap between second pattern 38 to be deposited and first pattern 32, as shown in Figure 3C. Next, second pattern material  $M_2$  is deposited through shadow mask 36 to result in the pattern for second pattern 38, as shown in Figure 3D, thereby producing an electromechanical contact of the present invention. As discussed above, either or both first and second pattern, 32 and 38, are the coatings of the present invention. The coatings are tuned to meet the requirements of the particular application. For example, by modifying the types and quantity of metals and dopants used in the present invention, electrically resistive and electrically conductive coatings are obtained.

Preferred dopant elements to be used in the coatings of the present application and which are particularly effective for use in coatings for electromechanical contacts include B, Si, Ge, Te, O, Mo, W, Ta, Nb, Pd, Ir, Pt, V, Fe, Co, Mg, Mn, Ni, Ti, Zr, Cr, Re, Hf, Cu, Al, N, Ag and Au; with Ti and W being preferred; and with Ti being particularly preferred. Most importantly, the deposition may be "tuned" to meet the properties required for a particular application. This is done by altering the concentration of metal dopant co-deposited with the carbon, hydrogen, silicon and oxygen. For increasing the electrical conductivity, increasing amounts of dopant may be included in the deposited coating.

The ability to tailor the amount of metal dopant in the diamond-like coatings makes it possible to fabricate a variety of electromechanical contacts with varying electrical requirement. It is believed that this "tunability" contributes to the coatings uniqueness for the present invention.

In addition to excellent adherence, the coatings used to coat the electromechanical contacts of the present invention have very high hardness and wear-resistance values. Known electromechanical contacts have hardness values below 1 GPa. By comparison, as shown in the examples below, the electromechanical contacts of the present invention coated with the carbon and silicon-containing coating disclosed above have hardness values, depending upon the

dopant selected and the dopant concentration, in the range of from about 6 GPa to about 40 GPa.

With respect to wear and scratch-resistance, the coated contacts of the present invention exhibited vastly superior performance than the known polyimide-based contacts that are easily scratched and thus prone to damage during assembly and repair. The improved hardness and wear-resistance of the contacts of the present invention obviates the need for lubrication; an omnipresent requirement with known contacts. Indeed, the coated contacts of the present invention when lubricated last about 30 times longer than the prior known lubricated contacts. The coating has a hardness value of from about 6 GPa to about 40 GPa.

In addition, the wear-resistance of the present coated contacts allows the resistive patterns to be made thinner than their presently known counterparts. Specifically, known technology, i.e. the screen printing process, does not permit the deposition of thinner resistive patterns. Such resistive patterns are limited to a thickness of approximately 10-20  $\mu\text{m}$ . However, the preferred coatings for electromechanical contacts of the present invention range in thickness from about 0.1  $\mu\text{m}$  to about 4  $\mu\text{m}$ . Further, known materials for resistive patterns, such as polyimide, palladium silver, or the like, have relatively low hardness values, requiring the coating to be thick in order to provide sufficient wear resistance. By making the resistive patterns thinner, they are less prone to vibration and shock effects, contributing to enhanced overall performance. In addition, due to the reduced thickness of the resistive patterns, less tension is required on the hoe-shaped contacts.

The coated contacts of the present invention display excellent thermal stability, operating at temperatures as high as 450°C in air and 800°C in an inert atmosphere, with the coated contacts showing no degradation.

As a result of the excellent coating adherence, resistance to temperature and humidity variations, and wear/scratch-resistance, the coated contacts of the present application are much less prone to corrosion and environmental damage compared to their polyimide contact counterparts.

In a further embodiment, the present invention relates to an electromechanical contact including a substrate, a diamond-like carbon and silicon-containing coating preferably coated to a thickness of from about 0.1  $\mu\text{m}$  to about 6  $\mu\text{m}$ , and a metal material, wherein the metal material is a diamond-like carbon and

silicon-containing coating preferably coated to a thickness of from about 0.1  $\mu\text{m}$  to about 0.25  $\mu\text{m}$ , which contains a metal dopant. The metal dopant may be selected from the group consisting of Ti, Cr, Au, and Ag.

In a still further embodiment, the invention relates to a method for making an electromechanical contact comprising providing a substrate and a vacuum deposition chamber, positioning the substrate within the chamber, and depositing a diamond-like carbon and silicon-containing coating.

The apparatus for carrying out the method of the present invention is illustrated schematically in Figure 1, as described above. The apparatus includes a hot-filament-triode plasmatron, a substrate holder and precursor delivery system. The coating process is carried out in a high vacuum deposition chamber. The high vacuum is achieved by roughing down the chamber with a mechanical pump followed by pumping with a high vacuum pump. The high vacuum pump can be a diffusion pump, turbo-molecular pump, cryogenic pump or other high vacuum pumps known in the state of art.

The method of the present invention can be carried out in a batch type process for small volumes where the substrates are mounted on a substrate holder inside the deposition chamber, deposition chamber is evacuated, deposition performed and the chamber is vented to remove the parts. For larger volumes, the method of the present invention can be done in air-to-air system. The air-to-air system comprises cleaning of parts, transport of parts to the deposition chamber, mechanized/vibratory loading of the parts on to the substrate holder, entry into a load-lock chamber, entry into the deposition chamber, coating of the parts, exit into a load-lock chamber, followed by exit into the atmosphere.

The substrates may have to be rotated, tilted and vibrated during mounting on the substrate holder. Vertical orientation is preferred to minimize particulate or debris accumulation and contamination of substrate surfaces. The deposition chambers are evacuated with low turbulence vacuum pumping to minimize particulate and debris being deposited on the substrate surfaces.

The chambers are evacuated to ultimate pressure of below  $10^{-5}$  Torr after loading the substrates. Argon gas is introduced into the chamber to raise the chamber pressure to  $10^{-3}$  Torr to  $10^{-4}$  Torr. The substrates are then argon ion etched inside the deposition chamber before coating contacts with the diamond-like carbon

and silicon-containing coating. The argon-ion etching is performed by single plate RF, DC, or PDC discharge in the  $10^{-3}$  Torr range. During the discharge a substrate bias of 0.3 KV to 5.0 KV can be used. The frequency of the RF and PDC is in the range of 90 KHz to 450 KHz. Argon ion etching can also be done at lower pressures (10<sup>-4</sup> Torr) by applying a substrate bias (RF, DC, or PDC - 0.3 to 5.0 KV) and creating a plasma with a hot filament. Here again, the frequency of the RF and PDC is in the range of 90 KHz to 450 KHz. The temperature of the hot filament is in the range of 2100°C to 2950°C with an AC voltage across the filament of 10V to 25V and with a DC filament bias of 70V to 150V.

Other ion sources known in the state of the art, such as Kaufmann type ion sources and RF coils sources, can also be used for generating the ions. In addition to argon-ion etching, chemical etching can also be accomplished for specific substrates such as plastics by introduction of small amounts of reactive gases such as oxygen during the in-situ cleaning process. The ion etching process removes the top few monolayers on the substrate surface which may consist of hydrocarbons, moisture, oxide layer and other contaminants and enhances adhesion of the diamond-like coating to the substrate surface.

Towards the end of substrate cleaning the pressure in the chamber is checked and adjusted to be in the  $10^{-3}$  Torr to  $10^{-4}$  Torr regime. Organosilicon precursors such as siloxanes are preferred precursor for C, H, Si and O. These precursors have 1 to 10 silicon atoms. The high boiling point precursor is directly introduced into the active plasma region using a microporous ceramic dispenser which is heated by the hot filament. The precursor can be mixed with other gases, both inert (Argon as feed gas) and active (methane, acetylene, butane etc.). The hot filament photon and electron emission causes evaporation, ionization and fragmentation of the precursor molecules. The precursor can also be introduced into the system using liquid delivery systems consisting of a flow controller, a heater and a dispenser as known in the state of the art. In the case of liquid delivery systems the source of electrons can be a hot filament isolated from the precursor delivery system. The use of isolated source of electrons can result in longer life of the electron source.

Metal containing beams can be generated by many methods: a) by thermal evaporation b) by ion sputtering, c) by ion beams, d) magnetron sputtering and the like. The metal beams are directed towards the substrate holder by

appropriate placement of the sources. Also, maintaining the pressure inside the chamber below  $10^{-3}$  Torr helps in minimizing the collision of metal containing beams with the residual gas molecules.

Variations of the above described diamond-like coating deposition process include: a) the use of sputtered silicon and oxygen gas as sources for Si and O, b) use of solid  $\text{SiO}_2$  as sources for Si and O, c) use of  $\text{SiH}_4$  and oxygen gases as sources of Si and O, d) use of graphite target, hydrogen and hydrocarbon gases as sources of C and H, e) use of metal containing organosilicon compounds as sources of C, H, Si, O and metal. Any combination of the above described methods is also possible.

The following examples serve only to further illustrate aspects of the present invention and should not be construed as limiting the invention.

### EXAMPLES

15

#### Example 1

Five alumina substrates with a screen printed conductive pattern of silver were ultrasonically cleaned in acetone, methylene chloride and methanol, dried with nitrogen gas and mounted on a 24" substrate holder. Control samples of silicon, glass, carbon steel, stainless steel and bare alumina substrates were also cleaned in a similar fashion and mounted on the substrate holder. A shadow mask with the desired resistor pattern was placed over the alumina samples. A titanium target was mounted on the magnetron. The chamber was evacuated to a ultimate pressure of  $8 \times 10^{-5}$  Torr. Argon gas was introduced in to the chamber to raise the pressure to 10 mTorr. The substrates were rotated at 7 revolutions per minute. An RF substrate bias was used and the substrate bias was ramped up to 400V. The substrates were argon ion-etched for 15 minutes at the above conditions. After 15 minutes of cleaning the pressure was lowered to  $4 \times 10^{-4}$  Torr. The triode plasmatron was ramped up to generate a plasma current of 1.0A. The siloxane precursor was introduced directly into the plasma and the magnetron was ramped up to 375 watts. The diamond-like coating deposition was performed under the above conditions for 90 minutes. This resulted in a 1.5 micron thick, highly adherent coating. The patterned resistor had an electrical resistance of 4.2 Kohms. The coating had a hardness of 13.6 GPa as measured by nanoindentation using the Oliver and Pharr Method.

**Example 2**

Two smooth alumina substrates ( $R_a \sim 50\text{\AA}$ ) were ultrasonically cleaned in acetone, methylene chloride and methanol, dried with nitrogen gas and mounted on a 24" substrate holder. A shadow mask with the desired conductive pattern was placed over the alumina samples. A chromium target was mounted on the magnetron. The chamber was evacuated to a ultimate pressure of  $8 \times 10^{-5}$  Torr. Argon gas was introduced in to the chamber to raise the pressure to 10 mTorr. The substrates were rotated at 7 revolutions per minute. An RF substrate bias was used and the substrate bias was ramped up to 400V. The substrates were argon ion-etch cleaned for 15 minutes at the above conditions. After 15 minutes of cleaning the pressure was lowered to  $4 \times 10^{-4}$  Torr. The magnetron was ramped up to a power of 500 watts. A patterned layer of chromium was deposited under the above conditions for 30 minutes. Following the chromium deposition the chamber was vented to the atmosphere. The chromium deposition resulted in a 0.5 micron thick chromium film. The shadow mask for the conductor pattern was removed. A second shadow mask with the desired resistor pattern was placed on the chromium coated alumina substrates. Control samples of silicon, glass, carbon steel, stainless steel and bare alumina substrates that were ultrasonically cleaned in acetone, methylene chloride, methanol and dried in nitrogen gas were mounted on the substrate holder. The chromium target was removed and a titanium target was mounted on the magnetron. The chamber was evacuated to a ultimate pressure of  $8 \times 10^{-5}$  Torr. Argon gas was introduced in to the chamber to raise the pressure to 10 mTorr. The substrates were rotated at 7 revolutions per minute. An RF substrate bias was used and the substrate bias was ramped up to 800V. The substrates were argon ion-etched for 15 minutes at the above conditions. After 15 minutes of cleaning the pressure was lowered to  $4 \times 10^{-4}$  Torr. The triode plasmatron was ramped up to generate a plasma current of 1.0A. The siloxane precursor 2,3,4-triphenyl-nonamethyl-pentasiloxane was introduced directly into the plasma. The diamond-like deposited coating was performed under the above conditions for 90 minutes. This resulted in a highly adherent Ti-DLN coating of 1.5 micron thickness. The patterned resistor had an electrical resistance of 6.1 Kohms.



### Example 3

A one inch square piece of silicon and one inch square glass substrate were ultrasonically cleaned in acetone, methylene chloride and methanol, dried with nitrogen gas and mounted on a 24" substrate holder. Control samples of silicon, glass, carbon steel and stainless steel were also cleaned in a similar fashion and mounted on the substrate holder. A shadow mask with the desired resistor pattern was placed over the one inch square of silicon and glass samples. A tungsten target was mounted on the magnetron. The chamber was evacuated to a ultimate pressure of  $8 \times 10^{-5}$  Torr. Argon gas was introduced in to the chamber to raise the pressure to 10 mTorr. The substrates were rotated at 7 revolutions per minute. An RF substrate bias was used and the substrate bias was ramped up to 200V. The substrates were argon ion-etched for 15 minutes at the above conditions. After 15 minutes of cleaning the pressure was lowered to  $4 \times 10^{-4}$  Torr. The triode plasmatron was ramped up to generate a plasma current of 0.5A. The siloxane precursor was introduced directly into the plasma and the magnetron was ramped up to 80 watts. The diamond-like carbon and silicon-containing coating deposition was performed under the above conditions for 10 minutes. This resulted in a highly adherent W-DLN coating of 0.12 micron thickness. The patterned resistor had an electrical resistance as measured by a multimeter of 37.6 Kohms.

### Example 4

One inch square alumina substrate was ultrasonically cleaned in acetone, methylene chloride and methanol, dried with nitrogen gas and mounted on a 24" substrate holder. Control samples of silicon, glass, carbon steel, stainless steel and aluminum substrates were also cleaned in a similar fashion and mounted on the substrate holder. A titanium target was mounted on the magnetron. The chamber was evacuated to a ultimate pressure of  $8 \times 10^{-5}$  Torr. Argon gas was introduced in to the chamber to raise the pressure to 10mTorr. The substrates were rotated at 7 revolutions per minute. An RF substrate bias was used and the substrate bias was ramped up to 400V. The substrates were argon ion-etched for 15 minutes at the above conditions. After 15 minutes of cleaning the pressure was lowered to  $4 \times 10^{-4}$

Torr. The triode plasmatron was ramped up to generate a plasma current of 1.0A. The siloxane precursor was introduced directly into the plasma and the magnetron was ramped up to 400 watts. The diamond-like coating deposition was performed under the above conditions for 135 minutes. This resulted in a highly adherent titanium-doped diamond-like coating of 2.3 micron thickness. The coating had a electrical resistance of 2.3 Kohms with a low temperature coefficient of resistance. Low temperature coefficient of resistance is defined as one between +1.0%/°C and -1.0%/°C . The coating had a hardness of 16.2 GPa as measured by nanoindentation and a compressive film stress of 578 MPa. The coating was dither tested in conventional setup used for testing automotive electromechanical contacts under dry conditions, and the film lasted 63 million cycles. The same coating was tested under a lubricated condition with a fluorocarbon lubricant, and only 10% of film thickness was worn away after 1.423 billion cycles.

#### 15 Example 5

One inch square alumina substrate was ultrasonically cleaned in acetone, methylene chloride and methanol, dried with nitrogen gas and mounted on a 24" substrate holder. Control samples of silicon, glass, carbon steel, stainless steel and aluminum substrates were also cleaned in a similar fashion and mounted on the substrate holder. A titanium target was mounted on the magnetron. The chamber was evacuated to a ultimate pressure of  $8 \times 10^{-5}$  Torr. Argon gas was introduced in to the chamber to raise the pressure to 10 mTorr. The substrates were rotated at 7 revolutions per minute. An RF substrate bias was used and the substrate bias was ramped up to 400V. The substrates were argon ion-etched for 15 minutes at the above conditions. After 15 minutes of cleaning the pressure was lowered to  $4 \times 10^{-4}$  Torr. The RF substrate bias was increased to 800V. The triode plasmatron was ramped up to generate a plasma current of 1.0A. The siloxane precursor was introduced directly into the plasma, and the magnetron was ramped up to 400 watts. The diamond-like deposited coating was performed under the above conditions for 90 minutes. This resulted in a highly adherent titanium-doped diamond-like coating having a 1.55 micron thickness. The coating had a hardness of 10.3 GPa as measured by nanoindentation and a compressive film stress of 341 MPa. The coating was wear

tested in conventional ball-on disk setup using a steel ball with a 10N load under dry conditions for 100,000 cycles. The coating had a wear factor of  $3 \times 10^{-7} \text{ mm}^3/\text{Nm}$ .

Although the invention has been described in detail for the purpose of illustration, it is understood that such detail is solely for that purpose, and variations  
5 can be made therein by those skilled in the art without departing from the spirit and scope of the invention which is defined by the following claims.

**WHAT IS CLAIMED:**

1. An electromechanical contact, comprising:  
a substrate; and  
5 a diamond-like coating comprising carbon, silicon, and a metal,  
wherein the coating forms a resistive pattern on the substrate.
2. The contact according to Claim 1, wherein the coating  
comprises carbon, hydrogen, silicon, oxygen and a metal.
- 10 3. The contact according to Claim 2, wherein the coating further  
comprises a dopant.
4. The contact according to Claim 3, wherein the dopant is  
15 selected from Groups 1-7b and 8 of the periodic table.
5. The contact according to Claim 3, wherein the dopant is  
selected from the group consisting of B, Si, Ge, Te, O, Mo, W, Ta, Nb, Pd, Ir, Pt, V,  
Fe, Co, Mg, Mn, Ni, Ti, Zr, Cr, Re, Hf, Cu, Al, N, Ag and Au.
- 20 6. The contact according to Claim 3, wherein the metal is  
titanium.
7. The contact according to Claim 3, wherein the metal is  
tungsten.
- 25 8. The contact according to Claim 2, wherein the carbon, silicon,  
hydrogen, and oxygen are obtained from the decomposition of an organosiloxane  
having from 1 to 10 silicon atoms.
9. The contact according to Claim 8, wherein the organosiloxane  
30 is a polyphenylmethylsiloxane.
10. The contact according to Claim 2, wherein the carbon, silicon,  
hydrogen, and oxygen are obtained from the decomposition of 2-3-4 triphenyl-  
nonamethyl-pentasiloxane

11. The contact according to Claim 2, wherein the carbon content of the coating is from about 40 atomic % to about 98 atomic %.

5 12. The contact according to Claim 2, wherein the carbon content of the coating is from about 50 atomic % to about 98 atomic %.

13. The contact according to Claim 12, wherein the hydrogen content of the coating from 0 to about 40 atomic % of the carbon concentration.

10

14. The contact according to Claim 13, wherein the hydrogen content of the coating is at least about 1 atomic % of the carbon concentration.

15 15. The contact according to Claim 3, wherein the carbon content of the coating comprises at least 40 atomic %, the hydrogen content is at least 1 atomic % of the carbon, and the sum of the silicon, oxygen and dopants together is greater than about 2 atomic % of the coating composition.

20 16. The contact according to Claim 2, wherein the ratio of carbon to silicon is from about 2:1 to about 8:1.

17. The contact according to Claim 2, wherein the ratio of silicon to oxygen is from about 0.5:1 to about 3:1.

25 18. The contact according to Claim 2, wherein the ratio of hydrogen to carbon is from about 0.01 to about 1.

30 19. The contact according to Claim 3, wherein the ratio of carbon to hydrogen is from about 0.01 to about 0.4, carbon to silicon is from about 2:1 to about 8:1, carbon to oxygen is from about 0.0375 to about 1.0, and carbon to dopants is from about 0.01 to about 1.5.

20. The contact according to Claim 2, further comprising a metal layer disposed between the substrate and the coating.

21. The contact according to Claim 20, wherein the metal is selected from the group consisting of Cr, Au, Ag, and Ti.

5 22. The contact according to Claim 3, further comprising a metal layer disposed between the substrate and the coating.

23. The contact according to Claim 22, wherein the metal is selected from the group consisting of Cr, Au, Ag, and Ti.

10

24. The contact according to Claim 1, wherein the substrate is selected from the group consisting of glass, brass, ceramics, polyimides, fluorocarbon polymers, thermoplastics, and pallidum silver.

15 25. The contact according to Claim 1, wherein the substrate has a pre-existing resistive pattern, whereby the coating resistive pattern is formed over the substrate resistive pattern.

20 26. The contact according to Claim 3, wherein the coating is deposited to a thickness of from about 0.1 microns to about 4 microns.

27. The contact according to Claim 26, wherein the coating has a hardness value of from about 6 GPa to about 40 GPa.

25 28. The contact according to Claim 26, wherein the coating has an electrical resistivity of from about 0.001 ohm-cm to about 200 ohm-cm and a low temperature coefficient of resistance.

30 29. The contact according to Claim 26, wherein the coating has a wear value of from about  $5 \times 10^{-9}$  mm<sup>3</sup>/newton-meter to about  $1 \times 10^{-5}$  mm<sup>3</sup>/newton-meter.

30. The contact according to Claim 3, further comprising:

a metal material surrounding the coating, wherein the metal material is a second diamond-like coating comprising carbon, silicon and a metal.

31. The contact according to Claim 30, wherein the metal material  
5 comprises carbon, hydrogen, silicon, oxygen and a metal.

32. The contact according to Claim 31, wherein the metal material further comprises a dopant.

10 33. The contact according to Claim 32, wherein the dopant is selected from the group consisting of B, Si, Ge, Te, O, Mo, W, Ta, Nb, Pd, Ir, Pt, V, Fe, Co, Mg, Mn, Ni, Ti, Zr, Cr, Re, Hf, Cu, Al, N, Ag and Au.

15 34. The contact according to Claim 32, wherein the dopant is titanium.

35. The contact according to Claim 32, wherein the dopant is tungsten.

20 36. The contact according to Claim 32, wherein the dopant selected from Groups 1-7b and 8 of the periodic table.

25 37. The contact according to Claim 32, wherein the coating is deposited to a thickness of from about 0.1 microns to about 4 microns.

38. The contact according to Claim 37, wherein the coating has a hardness value of from about 6 GPa to about 40 GPa.

30 39. The contact according to Claim 37, wherein the coating has an electrical resistivity of from about 0.001 ohm-cm to about 200 ohm-cm and a low temperature coefficient of resistance.

40. The contact according to Claim 37, wherein the coating has a wear value of from about  $5 \times 10^{-9}$  mm<sup>3</sup>/newton-meter to about  $1 \times 10^{-5}$  mm<sup>3</sup>/newton-meter.

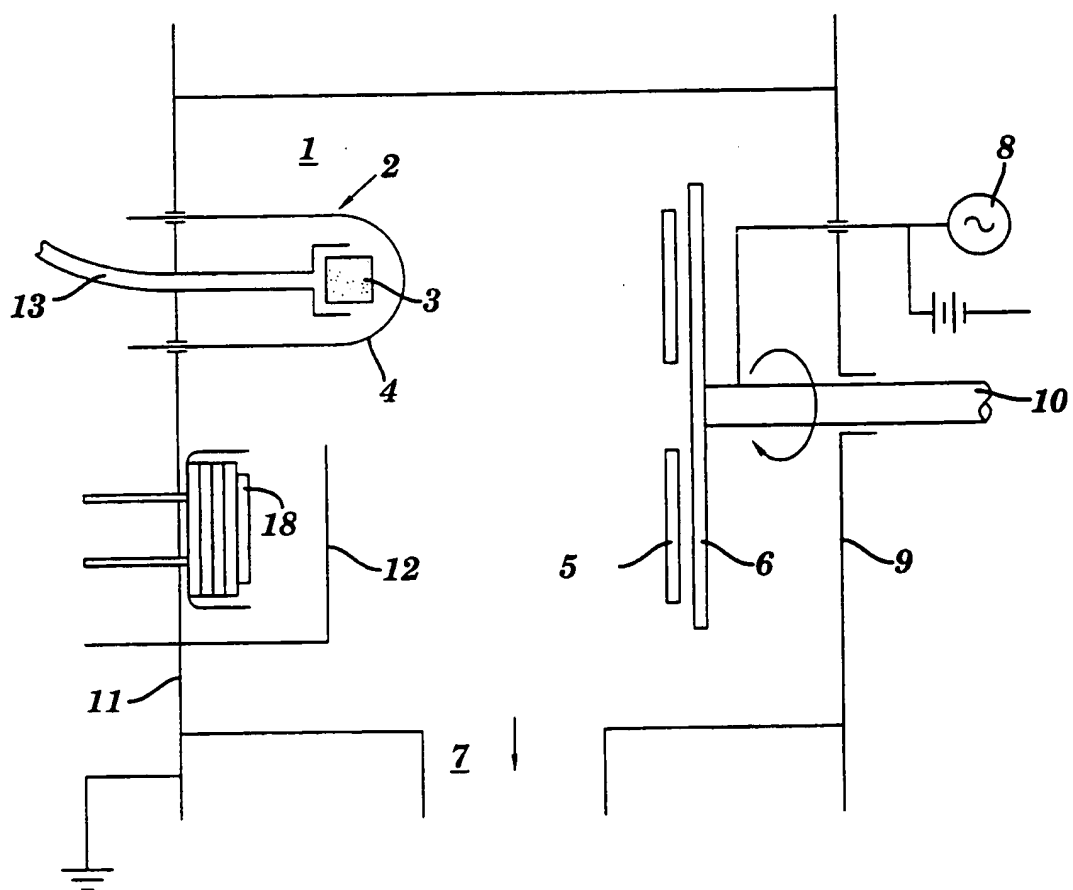
41. A method of making a wear-resistant electromechanical  
5 contact, comprising:  
providing a substrate; and  
applying the coating of claim 1 on the substrate in a resistive  
pattern.

10 42. The method according to Claim 41, wherein the coating has an electrical resistivity of from about 0.001 ohm-cm to about 200 ohm-cm.

43. The method according to Claim 41, wherein the coating has a  
wear value of from about  $5 \times 10^{-9}$  mm<sup>3</sup>/newton-meter to about  $1 \times 10^{-5}$  mm<sup>3</sup>/newton-  
15 meter.

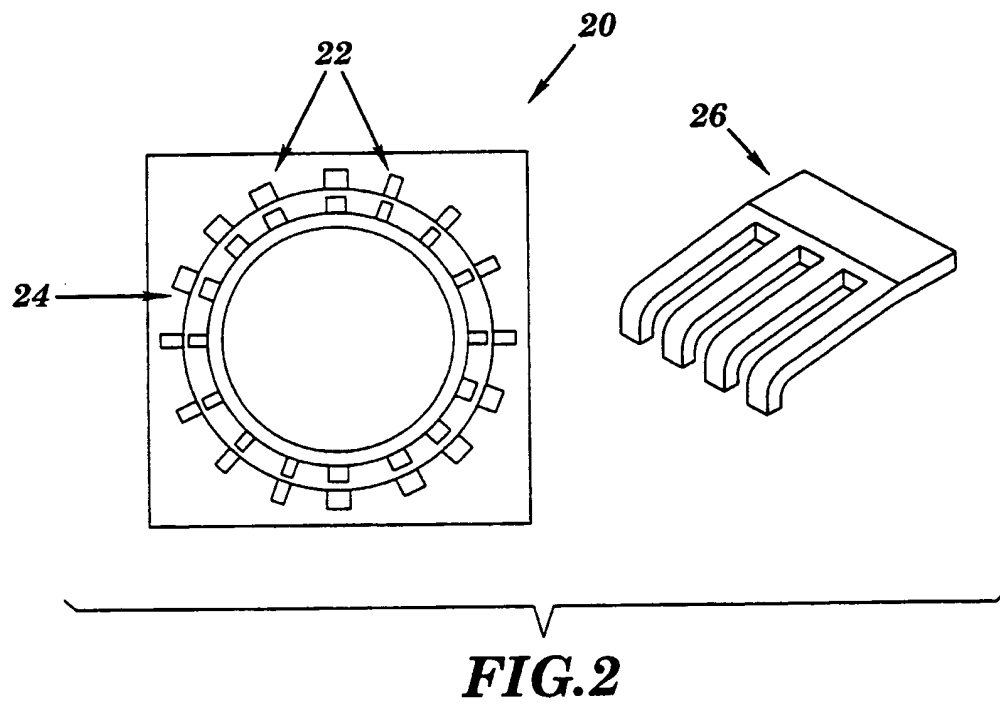


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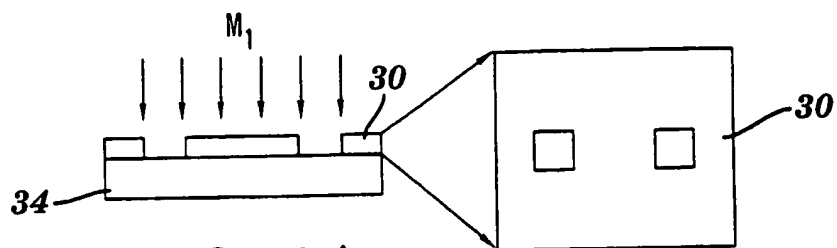


**FIG. 1**

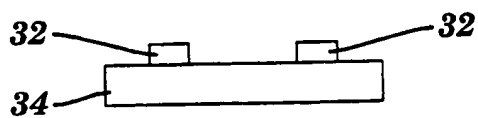
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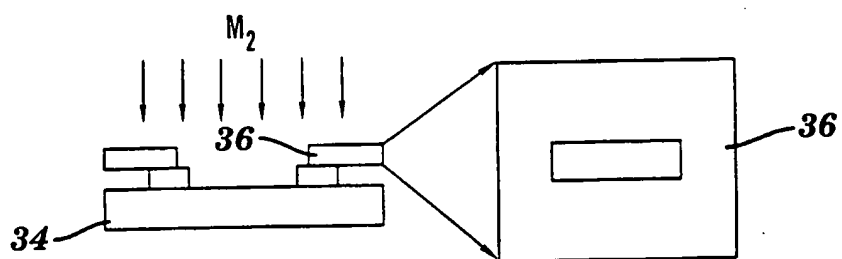
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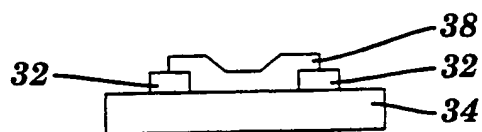
**FIG. 3A**



**FIG. 3B**



**FIG. 3C**



**FIG. 3D**

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US00/01295

<b>A. CLASSIFICATION OF SUBJECT MATTER</b>												
IPC(7) : H01L 21/00; H01C 7/10 US CL : 156/643, 646, 656; 437/181; 437; 29/612												
<b>B. FIELDS SEARCHED</b>												
Minimum documentation searched (classification system followed by classification symbols) U.S. : 156/643, 646, 656; 437/181; 437; 29/612												
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched NONE												
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) NONE												
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>												
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.										
Y	US 5,466,431 A (DORFMAN et al.) 14 November 1995 (14.11.1995), see entire document.	1-43										
Y	US 5,183,530 A (YAMAZAKI) 02 February 1993 (02.02.1993), see entire document.	1-43										
Y	US 5,317,302 A (YAMAZAKI) 31 May 31 1994 (31.05.1994), see entire document.	1-43										
Y	US 5,729,074 A (SHIOMI et al.) 17 March 1998 (17.03.1998), see entire document.	1-43										
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.												
* Special categories of cited documents: <table border="0"> <tr> <td>"A" document defining the general state of the art which is not considered to be of particular relevance</td> <td>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</td> </tr> <tr> <td>"E" earlier application or patent published on or after the international filing date</td> <td>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</td> </tr> <tr> <td>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</td> <td>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</td> </tr> <tr> <td>"O" document referring to an oral disclosure, use, exhibition or other means</td> <td>"&amp;" document member of the same patent family</td> </tr> <tr> <td>"P" document published prior to the international filing date but later than the priority date claimed</td> <td></td> </tr> </table>			"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	"E" earlier application or patent published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art	"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family	"P" document published prior to the international filing date but later than the priority date claimed	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention											
"E" earlier application or patent published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone											
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art											
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family											
"P" document published prior to the international filing date but later than the priority date claimed												
Date of the actual completion of the international search 14 April 2000 (14.04.2000)		Date of mailing of the international search report 16 MAY 2000										
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230		Authorized officer Nhunh Nguyen Telephone No. (703)305-0422										